High-power Broadband Reflectarray Antenna with Height Adjustment

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Abstract: To enhance the power capacity and bandwidth of antenna arrays, a high-power broadband reflectarray antenna with height adjustment has been proposed. The high-power reflectarray comprises reflective elements, a beam scanning control system, and a high-power feed source. In the design, the high-power feed source horn radiates GW-level high-power microwave radiation onto the reflective elements, which adjust their relative height through the beam scanning control system to compensate for phase shifts, enabling the beam to be steered in any direction. The reflective elements utilize a novel total internal reflection form, offering a simple structure that ensures the power capacity and aperture efficiency, as well as bandwidth of the antenna array. Full-wave simulation results demonstrate that this phased array can achieve a 360° phase shift, two-dimensional ±50° beam scanning, an aperture efficiency of 81%, a -1dB bandwidth of 10.8%, and a power capacity of 14GW.

Keywords: High Power; Broadband; Reflectarray

1. Introduction

With the advancement of high-power microwave technology, there is a pursuit for increased power capacity and gain, necessitating large-aperture array antennas. Waveguide slot antennas [1], helical array antennas [2], and lens array antennas [3] are among the primary focuses of high-power microwave antenna research and application in the country. However, complex power-dividing networks and narrow bandwidths limit their practical applications. On the other hand, high-power microwave radiation systems utilize phase shifters to achieve controllable beams, leading to high costs and low power capacity, or mechanical rotation of the array surface for beam scanning, resulting in bulky systems and slow battlefield response. There is an urgent need for high-power microwave antennas that are conformal, beam-flexibly controllable, compact, modular, adaptable to various platforms, with high power capacity, wide beam scanning range, simple feeding methods, and low profiles. High-power reflectarrays [4][5] can effectively address these issues, but when microstrip patch units are at resonance, the surface current is large, prone to electric field breakdown, leading to low power capacity. Therefore, enhancing the power capacity of planar reflectarray antennas is a crucial step towards their practical application. Against this backdrop, a broadband reflectarray antenna with height-adjusted elements has been designed, initially detailing the height-adjusted phase control system, followed by the design of the reflective elements, and finally, numerical simulation of the designed high-power reflectarray antenna.

2. Design and Working Mechanism of the Height-Adjusted Phase Control System

A height-adjusted phase control system has been designed for the high-power broadband reflectarray antenna to achieve rapid phase control [6]. The main components of the system are as follows:

- Reflective elements: Used to compensate for the phase required for beam scanning by ascending or descending.
- Linkages: Connect the reflective elements and facilitate their movement.
- Conversion devices: Drive the linkages.
- Motors: Drive the conversion devices, providing torque.
- Beam control boards: Control the motor rotation.
- Upper computer: Issues commands to the beam control board based on beam deflection.

As shown in Figure 1, the reflective elements, linkages, conversion devices, motors, beam control boards, and upper computer are connected in sequence to form the height-adjusted phase control system. During operation, the phase distribution of the array is first calculated. The phase curve of each unit is mapped according to the phase distribution to determine the required height, which in turn controls the motor's rotation steps. The motor rotates the conversion device, converting its rotation into vertical linear motion, pushing the linkages. The linkages, in turn, push the reflective elements to ascend or descend, compensating for the phase required for beam scanning and achieving beam deflection.

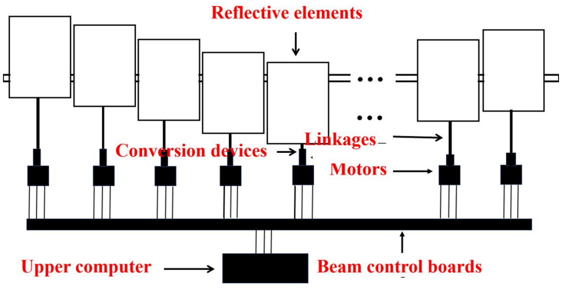

Figure 1. Reflectarray Phased Array System

3. Design of High-Power Reflective Elements

Microstrip patch antennas, favored for their small size, ease of integration, low profile, and simple structure, are the "darlings" of large array design. However, their power capacity is relatively low. To adapt to high-power microwave applications, the structure of the microstrip patch antenna is optimized, adopting a total internal reflection, non-resonant reflective element. The size of the reflective element is set to 15mm x 15mm, with a center frequency of 10GHz. The reflection phase and amplitude curves are obtained by simulating the reflective element in HFSS using master-slave boundary conditions and Floquet ports. As shown in Figure 2 and Figure 3, from Figure 2, there is a 360° phase shift within 0.1mm-16mm, and it is linear. From Figure 3, S11 is within -0.001dB, achieving total reflection.

4. High-Power Reflectarray Design

The design of the high-power reflectarray begins by determining the phase distribution, obtaining the corresponding height for each unit based on the phase curve, generating the array antenna model, and setting up the simulation environment. The phase distribution is obtained through a phase calculation formula, as follows [7]:

$$\Theta = k_0\left(d_i - \left(x_i\cos\alpha + y_i\sin\alpha\right)\sin\beta\right) \quad (1)$$

where Θ is the compensation phase required at each position, $k_0 = 2\pi/\lambda$ represents the wave number in a vacuum, λ is the wavelength, d_i is the distance from each unit in the array to the feed source, and α, β represent arbitrary beam pointing angles, x_i is the coordinate of the unit on the x-axis, and y_i is the coordinate on the y-axis.

The focal ratio, defined as the ratio of the antenna's focal length to its aperture, is F/D. A reasonable focal ratio is beneficial for enhancing antenna gain. In this paper, the focal ratio is $F/D = 0.95$. To reduce the impact of the feed horn on the array's radiation beam, an offset feeding method is adopted, with the feed horn located above the edge of the array. Microwaves are incident at an angle of 30° on a 20×20 array surface, as shown in Figure 4.

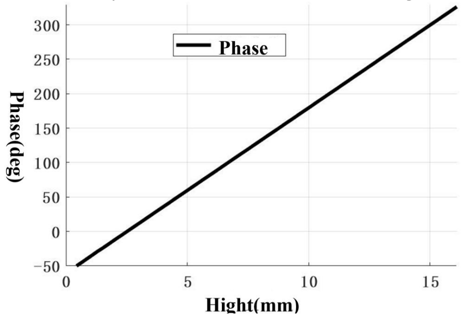

Figure 2. Reflection Phase

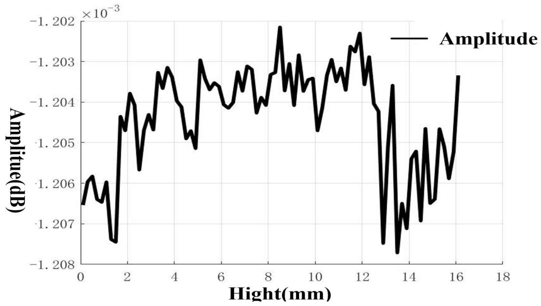

Figure 3. Reflection Amplitude

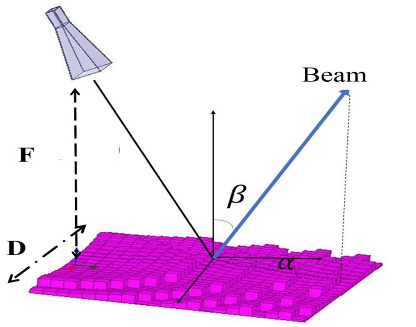

Figure 4. Array Model

The phase distribution is calculated using Matlab based on the phase compensation formula. The phase distributions at 0° and 30° are shown in Figure 5 and Figure 6.

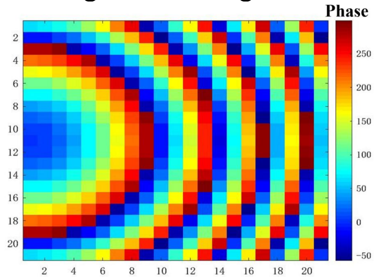

Figure 5. 0° Phase Distribution

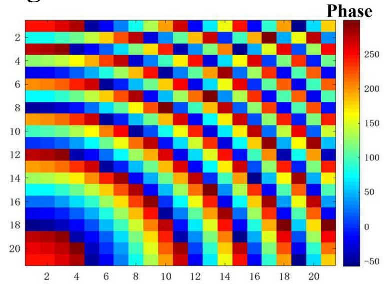

Figure 6. 30° Phase Distribution

5. High-Power Reflectarray Simulation Verification

The feed horn input power is set to 1W, radiating a linearly polarized wave with a center frequency of 10GHz. The far-field pattern at 0° is shown in Figure 7, with a gain of 28.3dB, and the calculated aperture efficiency is 81.1%. Figure 8 shows the bandwidth gain, indicating a -1dB bandwidth of 10.8% (9.43GHz-10.51GHz), demonstrating excellent broadband characteristics.

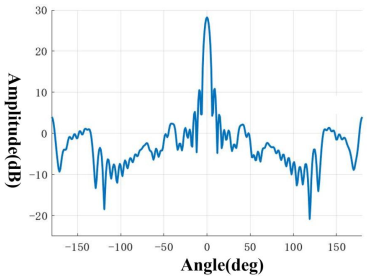

Figure 7. Far-Field Pattern

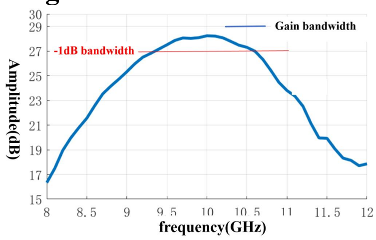

Figure 8. Gain Bandwidth

As shown in Figure 9, the electric field intensity distribution at 0° is such that the electric field intensity of the reflectarray is 352.5V/m. Based on the vacuum breakdown electric field of 55.2MV/m, the power capacity is 24.5G. To further investigate the performance of the height-adjusted high-power broadband reflectarray antenna, the paper plots the beam deflection pattern from 0° to 40°, as shown in Figure 10. The far-field patterns at intervals of 10° from 10° to 50° have gains of 27.99dB, 27.3dB, 26.18dB, 24.11dB, and 21.86dB, respectively. Additionally, a table of power reflectarray antenna deflection performance indicators is compiled, as shown in Table 1. Table 1 provides the gain and electric field intensity at different deflection angles. Based on the maximum electric field intensity (calculated using the vacuum breakdown electric field), the reflectarray antenna has a power capacity of at least 14GW.

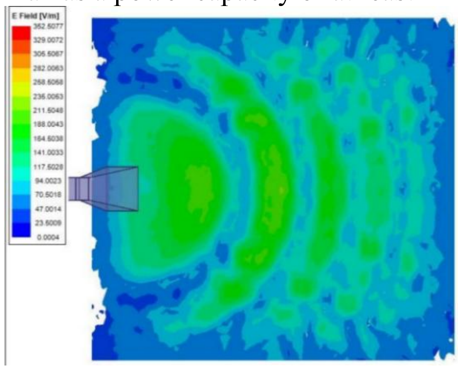

Figure 9. Electric Field Distribution Figure

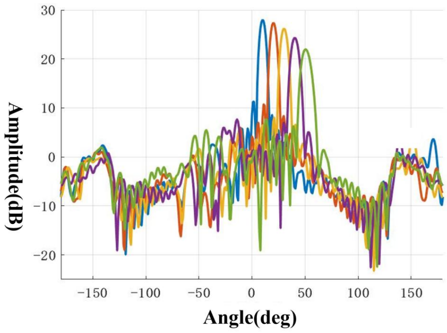

Figure 10. Beam Deflection Pattern from 0° to 50°

Table 1. High-Power Reflectarray Antenna Deflection Performance Indicators

Deflection Angle	Gain (dB)	Maximum Electric Field Intensity (V/m)	Power Capacity (GW)
0°	28.2	352	24.5
10°	27.99	283.2	38
20°	27.3	436.55	16.1
30°	26.18	430.76	16.8
40°	24.11	467.76	14

50°	21.87	400.84	19

6. Conclusion

This paper introduces a novel high-power broadband reflectarray antenna with height adjustment. The design of a 20x20 element array system has been completed, achieving two-dimensional beam scanning of ±50°. The aperture efficiency is 81.2%, with a -1dB bandwidth of 15%. In a vacuum environment, it can support a power capacity of at least 14 GW. This innovative design demonstrates significant potential for high-power microwave applications.

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